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1.	Your reference	PQ12,768
2.	Patent application number *(The Patent Office will fill in this part)*	9800220.7
3.	Full name, address and postcode of the or of each applicant *(underline all surnames)*	Central Research Laboratories Limited Dawley Road Hayes Middlesex UB3 1HH
	Patents ADP number *(if you know it)*	06097943001
	If the applicant is a corporate body, give the country/state of its incorporation	England
4.	Title of the invention	METHOD OF FORMING INTERCONNECTIONS BETWEEN CHANNELS AND CHAMBERS
5.	Name of your agent *(if you have one)*	QED Patents Limited
	"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*	Dawley Road Hayes Middlesex UB3 1HH
	Patents ADP number *(if you know it)*	07304538001
6.	If you are declaring priority from one or more earlier patent applications, give the country and the date of filing of the or of each of these earlier applications and *(if you know it)* the or each application number	Country / Priority application number *(if you know it)* / Date of filing *(day / month / year)*
7.	If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application	Number of earlier application / Date of filing *(day / month / year)*
8.	Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if: a) any applicant named in part 3 is not an inventor, or b) there is an inventor who is not named as an applicant, or c) any named applicant is a corporate body. See note (d))*	Yes

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Description	6	
Claim*(s)*	1	
Abstract	1	
Drawing*(s)*	11 +11	

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Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1 + 2
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature QED Patents Limited Date 6/1/98

12. Name and daytime telephone number of person to contact in the United Kingdom

Mr Keith Leaman, 0181-848-6633

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DUPLICATE

Method of Forming Interconnections between Channels and Chambers

This invention relates to a method of forming interconnections between channels and chambers, and more particularly to such a method for use in micro-engineered fluidic devices.

Micro-engineered devices may be used to transport and control fluid flow. Such devices may be used in a variety of applications including chemical and physical analysis, chemical processing, and heat transfer. Micro-engineered fluidic devices for use in the transport of immiscible fluids are described in International Patent Applications WO 96/12540 and WO 96/12541.

The advantages of using micro-fluidic devices containing channels and chambers are:

1. Only small sample sizes are needed for analysis; and
2. Transport distances for chemical processing of fluids are usually small; and
3. Heat transfer is improved.

Channels and chambers are usually formed on planar substrates, and are hereinafter referred to as "channels". There is a need for the linking of individual channels for applications which require a high fluid throughput, as fluid flow in conventional micro-engineered devices may be very low. Channels may be produced by forming grooves or depressions on one or more faces of a substrate. Such substrates may then be bonded together. Vias may also be formed in the substrate, and may connect to channels formed therein.

A number of known methods are used to form channels on the faces of planar substrates. These include:-

1. Etching using mask patterns defined by a lithographic process such as photolithography, screen printing, or direct writing; or
2. Cutting, milling, or drilling substrates by spark erosion, or laser ablation; or
3. Deposition or building up of layers on substrates according to patterns defined by lithographic processes; or
4. Electroplating through printing or photo-defined mask layers, including the use of X-ray lithography, as in LIGA (Lithographic Galvanoformung Abformung); or
5. The build up of substrates by bonding lamina, some of which may be cut to define a pattern of grooves or depressions; or
6. Mould replication or stamping of substrates defined by any of the above processes.

A common process is to form a fluid-handling micro-engineered device by anodic bonding of glass and silicon substrates having channels formed on one or both of the substrates.

Arrangements are known in the prior art for forming external connections and interconnections in substrates. External connections to channels are achieved by vias passing through to external faces of substrates, or by having channels extend to the edge of one or more of the substrates. Vias may be formed through one or more of the substrates to form interconnections between the channels. For simple devices with few external connections it is adequate to employ these methods. Methods for connecting capillaries to channels extending to the edge of a device composed of one or more substrates are described in UK Patent Application No. 9625491.7.

It is well established for electronic devices, that minimisation of the number of external input/output connections to arrays of charge pathways on a single substrate requires the routing of connections perpendicular to the substrate plane. This is achieved through the use of vias. The same topological requirements apply to fluidic devices where various feed and exit pathways connecting to channels should not intersect with each other, other than at the channel itself. For complex devices, a large number of external connections may be required.

Devices with vias and connections in multiple planar substrates correspond to the topological forms used to provide the dense connectivity required for integrated electronic devices. Within such electronic devices, charge pathways are defined in solid, self-supporting materials. The layers of material are usually thin enough to enable sufficient planarity to be maintained, allowing deposition, photolithography and etching to be carried out with good results.

In micro-fluidic devices, channels and vias are generally of larger dimensions than corresponding pathways and vias in integrated electronic devices. Channels are not self-supporting, as are the pathways in integrated electronic devices, because the formation of a channel, or a via, involves removing a volume of the substrate. Manufacture of channels and vias therefore contributes to fragility of the device, lowering yield during fabrication. This is especially true for vias, as they are formed perpendicular to the substrate plane. In addition, the difficulty of etching high aspect ratio vias (that is, a via whose length through the substrate is greater than its width) requires that the lateral dimensions of vias in the substrate plane are similar to (or often greater than) the thickness of the substrate in which they are formed. This last constraint may be overcome

by use of techniques such as laser ablation or trench etching, but such techniques are expensive and not widely available.

It is particularly difficult to photo-define and etch mask layers within the area of a narrow channel formed by a previous fabrication sequence in a micro-fluidic device. This constraint dictates that channels for micro-fluidic devices fabricated by conventional procedures are produced with a relatively low density. This is especially true for vias. Consequently, the cost per device is increased.

Typically, the density of channels formed on a substrate cannot be greater than that indicated in Figure 1, where a is of the order of the thickness of the substrate. This applies to micro-contactor arrays with channels connecting to vias produced by anisotropic or isotropic etching of a substrate. It is therefore desirable that a way of allowing interconnection and manifolding of channels is found, without the problems of low density of channels, fragility of the device, or poor manufacturing yield.

An aim of the invention is to overcome the aforementioned problems by providing a method of constructing interconnections and/or manifolds in substrates, particularly, but not exclusively, for use in micro-fluidic devices.

According to the present invention there is provided a method of connecting channels formed in a plurality of layered substrates by making at least one cut in at least one external face of said layered substrates, said cut being of sufficient depth to intersect the base of at least one channel in a substrate, such that only the required interconnections are made by each cut.

Preferably substrates are bonded before cuts are made, in order to maintain the physical integrity of a device incorporating the invention.

Cuts may be produced by micro-engineering sawing methods, which can be controlled to within 10 μm. Alternatively, it is possible to use mechanical milling, as long as the equipment used is of relatively high precision. Laser ablation, or photolithography and chemical etching may also be applied to produce the manifolding channels. Although in general, mechanical cutting or milling systems are preferred.

The channels formed on a substrate may be straight and/or curved.

The invention may be incorporated into a micro-fluidic (or other) device.

Fluids used within the device may either be miscible or immiscible. Aqueous and/or organic material may be used within the device.

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying Figures, wherein:-
Figure 1 shows a plan view of channels and chambers formed on a substrate, known in the prior art;
Figure 2 shows a cross-section of two planar substrates containing channels;
Figure 3 shows a cross-section of two bonded planar substrates containing channels;
Figure 4 shows a plan view of two bonded planar substrates shown in Figure 3;
Figure 5 shows a cross-section along line v-v' of Figure 4, where manifold cuts have been made in the substrates, in accordance with the present invention;
Figure 6 shows a plan view of two bonded planar substrates shown in Figures 3 to 5, where manifold cuts have been made in the substrates;
Figure 7 shows a cross-section of two bonded planar substrates along line v-v' of Figure 6;
Figure 8 shows a cross-section of a further embodiment of the invention showing two bonded planar substrates containing channels, where manifold cuts have been made in one substrate only;
Figure 9 shows an oblique view of the embodiment shown in Figure 8;
Figure 10 shows an oblique view of a further embodiment of the present invention; and
Figure 11 shows a plan view of a device incorporating the invention;

Referring to Figure 2, channels 14 are formed on a surface of planar substrate 10, which in this case is glass. Channels 15 are also formed on a surface of planar substrate 12, which is this case is silicon. Vias needed to interconnect the individual channels are not formed at this stage. Substrate layers 10 and 12 are then bonded together, as shown in Figure 3, to form channels 14 and 15. From Figures 3 and 4, it can be seen that the channels 14 in substrate 10 overlap channels 15 in substrate 12, to provide regions where fluids flowing in the respective channels 14, 15 contact at an interface 18.

Interconnections or manifolds to groups or arrays of channels 14 or 15 are formed by cuts 19, 20 made into one or more of the external faces of the bonded substrates 10 and 12, see Figures 5 and 6. The position and depth of these cuts is such that only required connections to respective channels 14 or 15 are made by each cut. Cuts made to substrate 10 should not extend deeply into substrate 12 in order to maintain the physical integrity of the assembled device.

Two methods for forming manifolds are discussed here. Figure 7 shows a first embodiment, where the manifolds 19 and 20 are cut in both substrate layers 12 and 10 respectively, and are offset. Cut 19 is made through substrate 12 only, to intersect channels 15. Cut 20 is made through substrate 10 only, to intersect channels 14. Figure 8 shows a further embodiment, where manifolds 20 and 21 are cut in the same substrate 10. Cut 20 is made through substrate 10, and is deep enough so that it intersects with channels in substrate 12. Cut 21 is also made through substrate 10, but its depth is less than that of cut 20, so that it only intersects with channels in substrate 10.

Where both substrates contain cuts, as in Figure 7, they should be offset, or positioned so as not to weaken the device. Formation of the interconnections generally involves at least some of the cuts through a substrate sufficiently to intersect the base of channels 14, 15 to be linked, and not continuing through to the interface 18 between bonded substrates 10, 12.

Where one of the substrates is transparent (substrate 10 in this case), it is advantageous to form all the manifold cuts through the transparent substrate, as in Figures 8 and 9. This allows more precise alignment of the cuts with the channels on further substrate layers.

The examples shown diagrammatically in Figures 2 to 9 are that of a micro-contactor. Similar steps may be taken to form other micro-fluidic devices from various planar substrates, provided that such substrates can be bonded and accurately cut. For example, in Figure 10, substrate 11 having manifold cuts 22, is bonded to substrates 10 and 12, which themselves contain manifold cuts 19 and 21. The resulting device has an increased manifold cross-section, and flow capacity is increased.

The depth of a cut 19, 20, 21 is not critical, as long as it deep enough to intersect with the channel which is to be connected with the cut, and does not pass far enough into a further substrate to weaken the assembly. For a micro-contactor, it is required that the manifolding connections do not cross the interface between the channels 14 and 15. If manifolding connections cross the interface, fluids tend to mix, and establishment of a stable fluid interface position is prevented. This is important for manifolding positions 21 shown in Figure 8, where pairs of contactor channels 14 and 15 intersect the plane of the manifold cut. Here it must be ensured that the depth of the cut is limited to a range sufficient to intersect predetermined channels 14 and 15 etched into the substrate being cut, while not allowing the cut to reach the interface between the substrates.

The restriction on the depth of manifold cuts applies to structures other than micro-contactors.

Figure 11 shows a schematic plan view of a device having a number of channels 14, 15 and manifold cuts 20, 21. The structure of the device is the same as that shown in Figures 8 and 9. Organic material passes through channels 15 formed in silicon substrate 12 via manifolding cuts 20. Cuts 20 pass through glass substrate 10 and silicon substrate 12 in order to intersect channels 15 formed in the silicon substrate 12. Aqueous material flows in channels 14 formed in glass substrate 10 via manifolding cuts 21. Here the organic material used in a mixture of Xylene and TBP (tributylphosphate) containing dissolved iron ions (Fe^{3+}), and the aqueous material is hydrochloric acid. Where channels 14 and 15 meet, the aqueous and organic materials come into contact. There is a transfer of iron ions from the organic material to the aqueous material. This reaction is an example of a liquid-liquid solvent extraction process and is used, for example, in the pharmaceutical and nuclear industries. The organic and aqueous materials then exit from the device.

Devices produced using this method have 120 micro-contactors of length 14mm, formed in an area of substrate 50 mm square. This is approximately ten times the density of channels achievable using past methods of etching through a substrate. Fluid flow and transfer rates for this array of channels have improved by a factor of 120 over the methods in the prior art.

The invention has been described by way of a number of embodiments and it will be appreciated that variation may be made to these embodiments without departing from the scope of the invention.

Claims

1. A method of connecting channels formed in a plurality of layered substrates by making at least one cut in at least one external face of said layered substrates, said cut being of sufficient depth to intersect the base of at least one channel in a substrate, such that only the required interconnections are made by each cut.

Abstract

A method of forming interconnections between channels and/or chambers for use in a micro-fluidic device. Two planar substrates 10, 12 (usually glass and silicon respectively) having etched channels 14, 15 are bonded together to form volumes 16 where the channels 14, 15 overlap. A manifolding cut 20 is then made through the glass to intersect channels 15 in the silicon layer. Another cut 21 is made through the glass, intersecting glass channels 14 only. An organic solution is passed into cut 20, and flows through silicon channels 15. An aqueous solution is passed into cut 21, and flows through glass channels 14. The solutions meet in the region 16, where matter is transferred from one solution to the other.

Figure 1

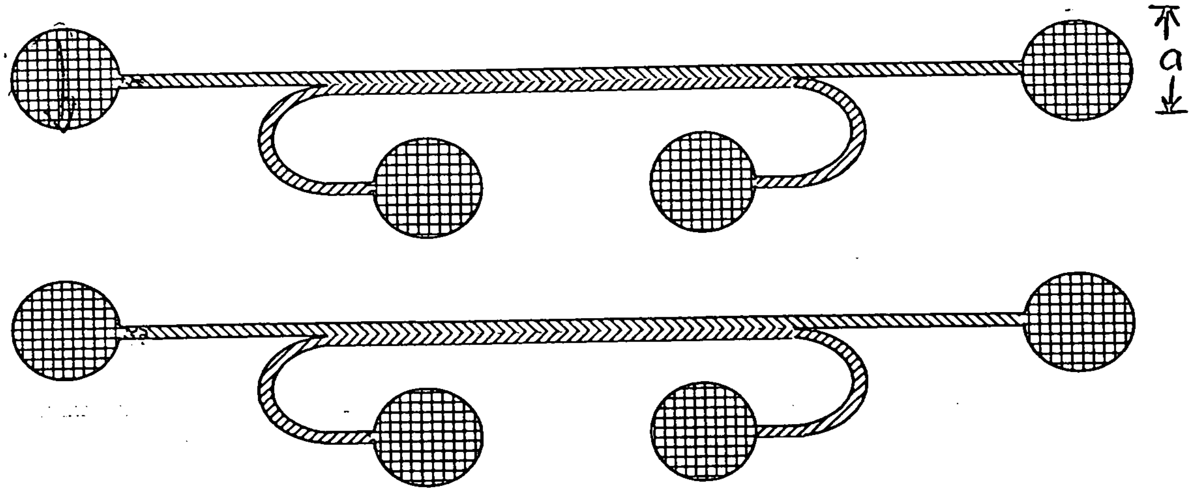
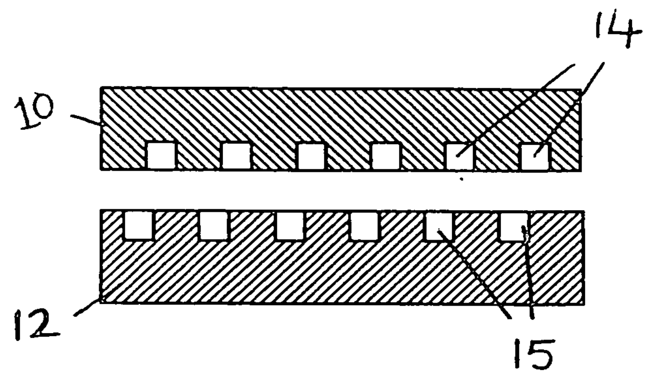


Figure 2



2|11

Figure 3

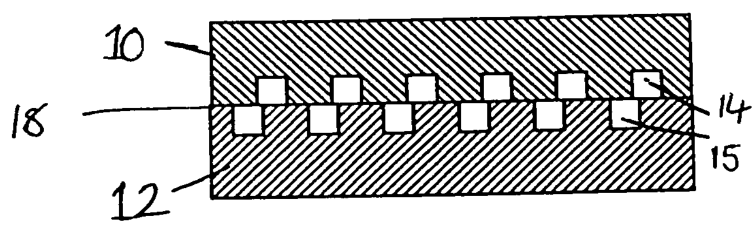


Figure 4

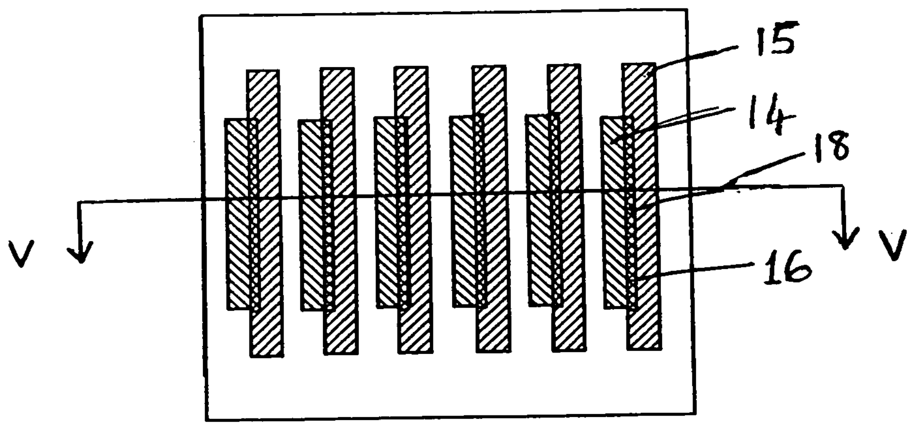


Figure 5

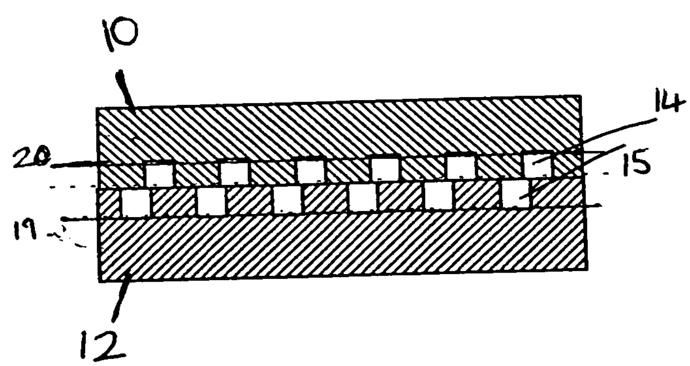


Figure 6

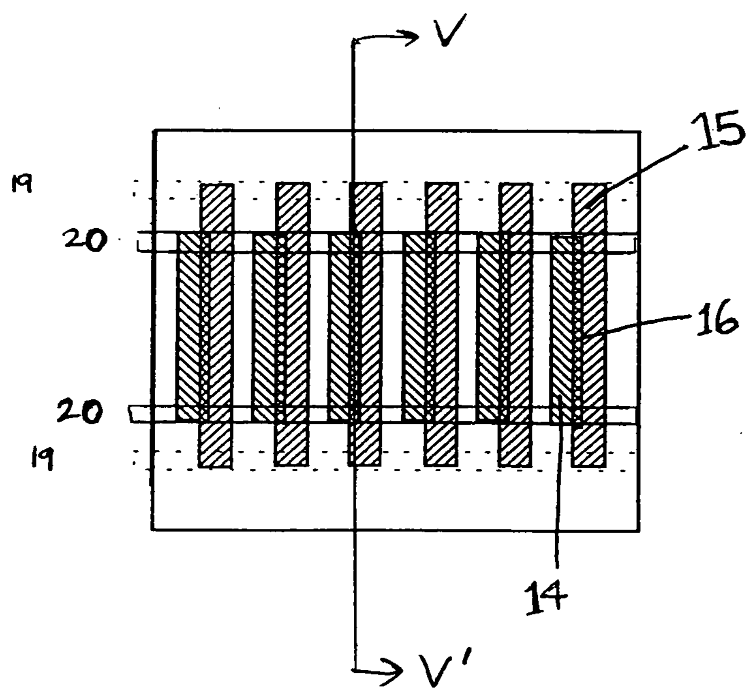


Figure 7

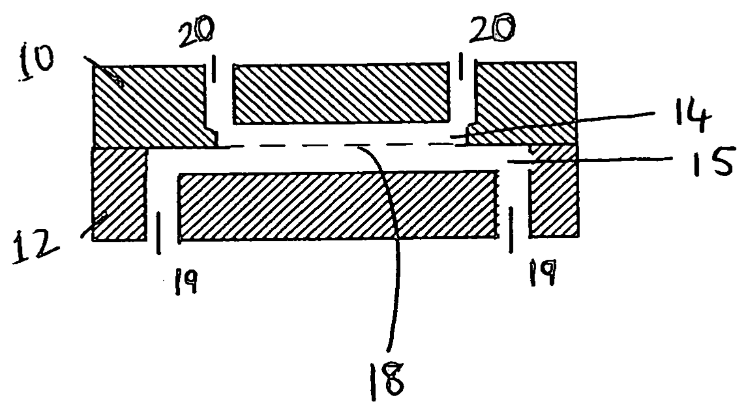


Figure 8

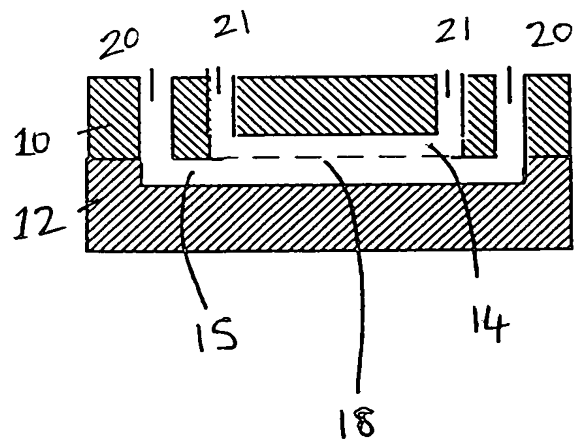


Figure 9

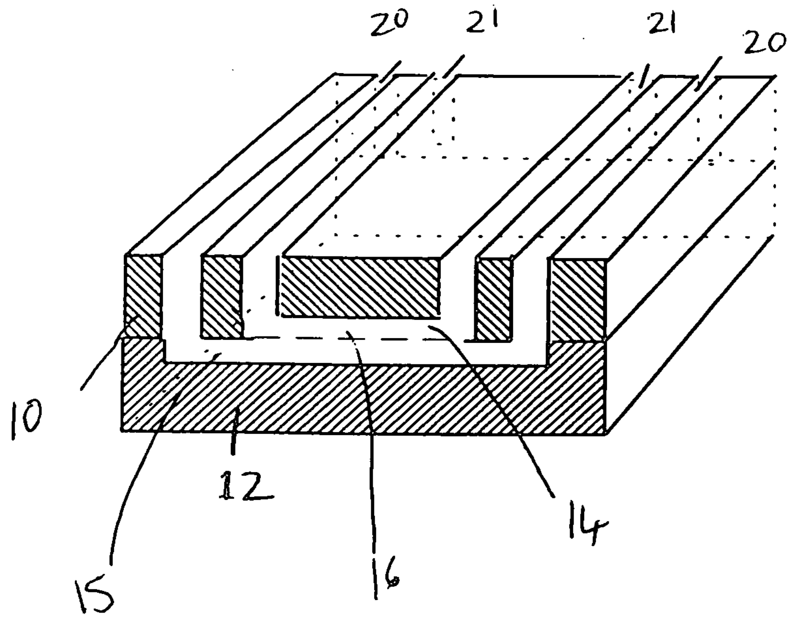


Figure 10

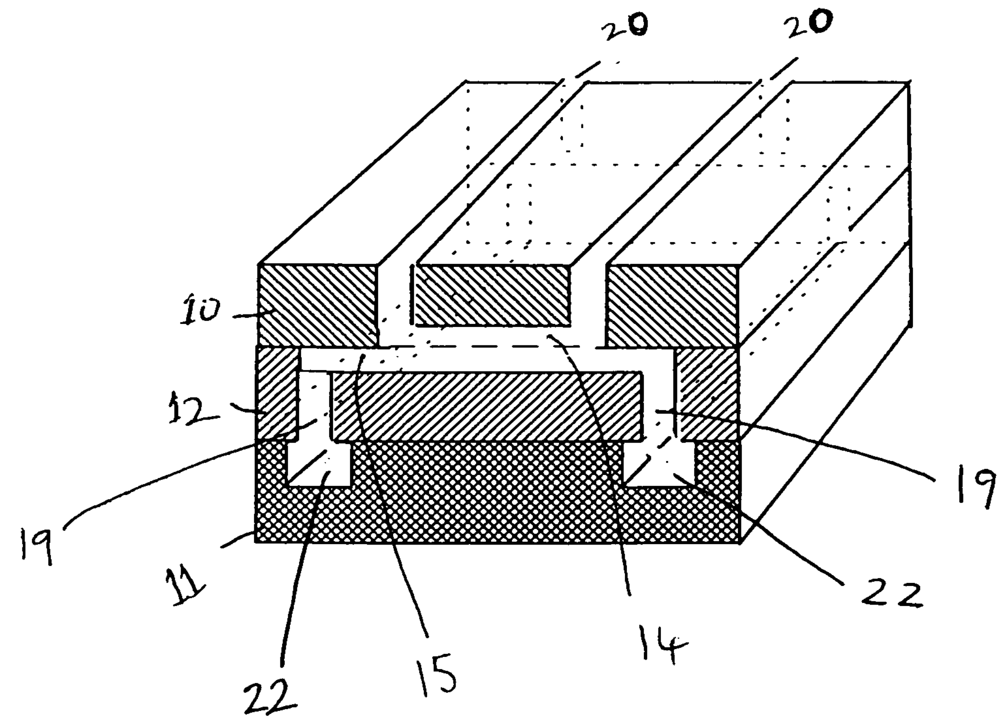
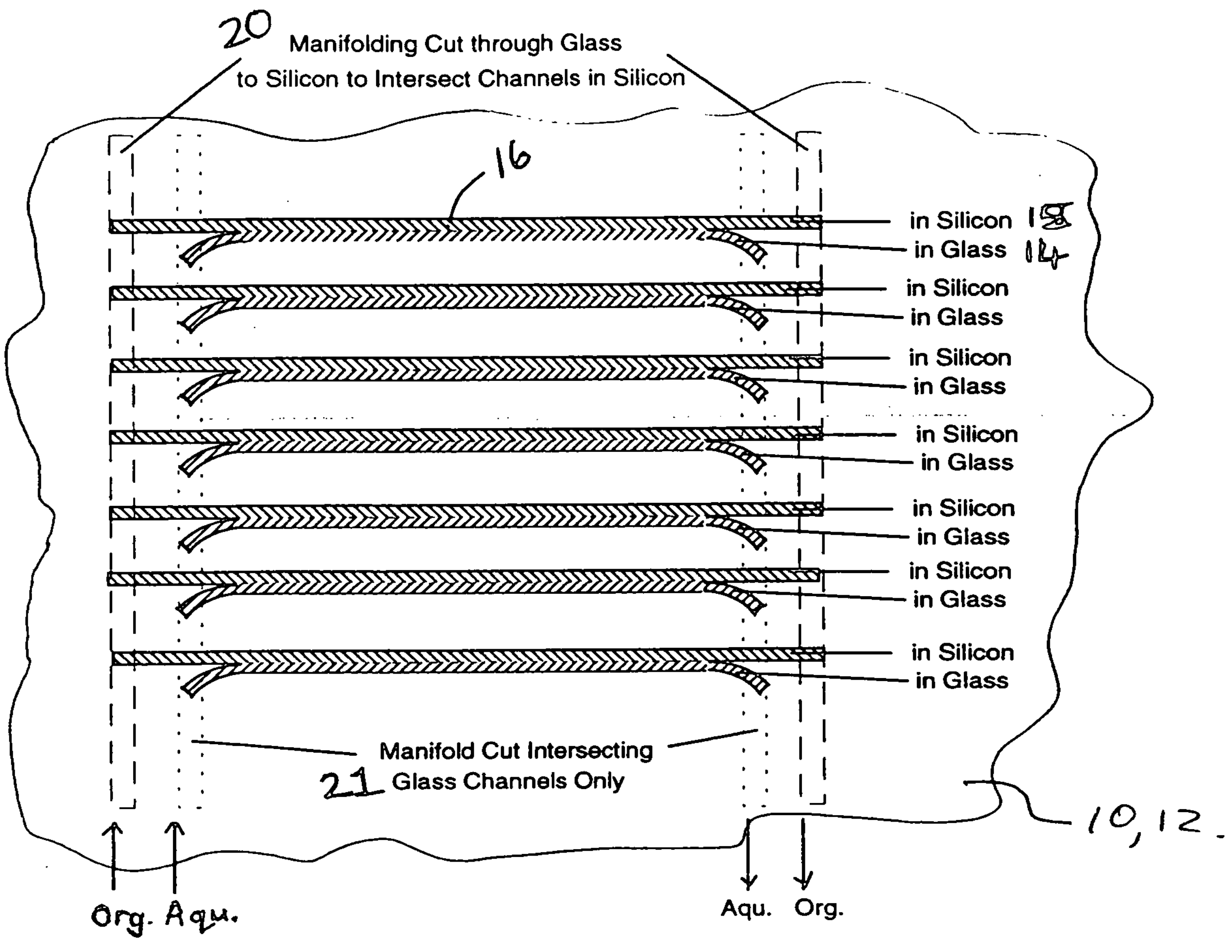


Figure 11


20
Manifolding Cut through Glass
to Silicon to Intersect Channels in Silicon
16
in Silicon 18
in Glass 14
in Silicon
in Glass
in Silicon
in Glass
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in Glass
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Manifold Cut Intersecting
21 Glass Channels Only
10,12.
Org. Aqu.
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